Variability along the Frontier

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Variability along the Frontier: Stable carbon and nitrogen isotope ratio analysis of human remains from the Late Roman-Early Byzantine cemetery site of Joan Planells, Ibiza, Spain

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Abstract

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope analysis of human bone collagen from 38 individuals was undertaken to assess diet at the Late Roman-Early Byzantine (AD 300-700) cemetery site, Joan Planells, in Ibiza, Spain. The results ($\delta^{13}C$=-18.7±0.5‰ and $\delta^{15}N$=10.1±1.3‰) that the diet of this population was derived predominantly from C_3 terrestrial resources; plant foods were likely dietary staples along with meat and/or dairy produce comprising an important component of diet. Variation in stable isotope ratio values suggest individual differences in diet. Two individuals, both males, are statistical outliers with distinctive $\delta^{15}N$ values (14.4‰ and 14.8‰) that point to significant consumption of marine resources. Females, on average, have higher $\delta^{13}C$ values than males. The parsimonious explanation for this observation is the greater inclusion of C_4 resources such as millet in the diets of females. Comparison of the diet of the Joan Planells population with other Late Roman period sites on the Hispanic mainland and other parts of the Mediterranean region suggests that populations may have been responding to a combination of socio-political and environmental factors that could have included Roman influence of food consumptive practices in some of these distant locales.

1. Introduction

Ibiza, one of the westernmost of the Balearic Islands, is located near the confluence of the Mediterranean and Atlantic Seas. Colonized by the 3rd millennium BC, the occupation history of Ibiza has been marked by successive waves of invasion and migration (Pomeroy 1976; Curchin 1991; Márquez-Grant 2005).

From the late 1st century BC until at least the late 3rd century AD, the social, economic and political structures throughout Europe, Asia and North Africa were influenced and altered, to a greater or lesser extent, by the expansion of the Roman Empire (Pericot Garcia 1972; Woolf and Gosden 1997). Ibiza came into the sphere of Roman influence in the mid-2nd century BC following the collapse of Carthage in 146 BC. Remaining largely politically and economically autonomous for much of the following century it became a municipality of Rome in AD 70 (Curchin 1991). While Ibiza became more strongly connected to Roman exchange networks, the evidence at Joan Planells dates to the 3rd to 7th centuries. These political and economic transformations were happened at a time called the Roman Warm Period, which saw the development of Roman civilization across the Western Mediterranean during a period of quiet storm activity. This period was succeeded by a period of the highest storm activity witnessed in this part of the Western Mediterranean in over 3 millennia (Degei et al. 2015). It is important to emphasize that climate and paleoecological studies have corroborated that the North Atlantic Oscillation (NAO) was a regional mechanism driving natural in the environmental fluctuation of the western Mediterranean during the Late Holocene (Lamb 1995; Nieto-Moreno et al. 2011, 2013). With these dramatic shifts happening, this paper contextualizes how the Roman influence in the region during the 3rd to 5th centuries (and continuing into the 7th century) was impacting the island of Ibiza, while other socio-political and environmental transformations were occurring. As diet and food consumption are important interlocutors for political, cultural and social exchange, this isotopic dataset provides ideal evidence to consider how the population in the Late Roman period were mitigating change.

Carbon and nitrogen stable isotope analysis of human bone collagen, an established method of investigating diet in past populations, was used to determine food consumption patterns in a Late Roman-Early Byzantine cemetery population at Joan Planells, Ibiza. In Late Roman times, the Iberian Peninsula is considered an essential region in the Imperial economy, which makes this study an essential contribution of data to the growing corpus of information on diet and dietary change in prehistoric and early historic Ibiza (Kulikowski 2004).

2. Joan Planells – Historical, Environmental and Archaeological Background

Joan Planells is a large cemetery site in Eivissa, Ibiza (Figure 1). As mentioned above, the island was first impacted by Roman expansion in the 2nd and 3rd centuries. During the time that this island was in the sphere of Roman influence, there was relative economic stability, but from the 4th century onward the Roman presence in the Iberian Peninsula experienced economic crisis and political break down ensued (Kulikowski 2004). With this economic crisis, the Atlantic commerce deteriorated rapidly.

During the 3rd to 5th centuries and into the 7th century, the Iberian Peninsula experienced important environmental changes. In Galicia, from the 2nd to 4th centuries, temperature and humidity conditions were optimal for agriculture, providing good growing seasons for most of the crops (Lopez Costas and Muldner 2016). When there were crop failures, millet and fish/shellfish were alternative foods sources. The marine resources exploited are an important contribution to Late Roman/post-Roman diet and may have been specific to the local perspective (Lopez Costas and Muldner 2016).

Prior to its use as a cemetery the site was an urban area used for pottery production (Esquembre Bebia et al. 2005; Martinez 2011; Girdwood 2012). The site is 36 m by 14 m in size and only a portion was excavated. The remains of 74 individuals were recovered in both single cist and multiple burials, some with comingled remains, and from a small number of simple pit burials (Martinez 2011). Individuals were placed in supine position and accompanied by few graves goods (Martinez 2011; Graziani Echávarri 2013). The small number of artifacts that were found in association with the skeletal remains indicate that this necropolis was in use from the Late Roman period, c. 3th–5th century AD, and continued to be used until the end of the Byzantine period, in the 7th century AD.

FIGURE 1 HERE

Sex and age were assessed and recorded under the supervision of one of the authors (EK). Standard methods for sex estimation utilizing the morphological features of the pelvis and cranium were employed wherever possible with the inclusion of metric techniques (Buikstra and Ubelaker 1994). Discriminant functions based on cranial and postcranial measurements were also employed to classify individuals when the pelvis was not available. The discriminant functions used for sex estimation was derived from a pooled sample from Ibiza of the same period and not from the American Standards. At first, sex was estimated using pelvic morphology and from these estimates discriminant functions were developed for long bones (e.g. femur) and teeth using bootstrapping to account for sample size bias. The individuals with over 80% posterior probability of correct classification were considered reliable while anything under 80% was considered unknown. This information provided the demographic information necessary to sample the 38 individuals that were analyzed for isotopes, in which males, females and children were considered for the study. Of the 74 individuals recovered from Joan Planells, 43 were adults, 7 were juveniles and 24 were of unknown age at death (García-Donas et al. 2014). Sex estimation was possible for 25 individuals with 11 males and 14 females (García-Donas et al. 2014). Indicators of degenerative joint disease, including Schmorl's nodes, were found to be more common in females than among the males, whereas trauma and metabolic ailments were more prevalent in males (see García-Donas et al. 2014 for more details). The preservation of the Joan Planells assemblage was poor, and the remains were highly fragmented. Many of the burials were weathered and the bone was cracked, which made the collection of samples for isotope analysis difficult. The population of Joan Planells appears to be from a local area, as the community buried in the cemetery includes men, women and children. Most evidence from ceramic remains and from textual records suggest that this site was urban, but this is not completely corroborated. The dietary evidence that is present below sheds some light on the kinds of patterns related to status and identity in relation to food consumption.

3. Reconstructing Diet

3.1 Historical Sources

Documentary sources indicate that in the Mediterranean region in the 2nd to 7th centuries AD diet was based largely on cereals (principally wheat and barley as well as millet, rye and oats), olive oil and wine, as well as legumes, such as lentils and chickpeas (Garnsey 1999). As the principal staple in the Mediterranean diet, wheat was often imported/exported throughout the Roman and Byzantine empires (e.g. Curchin 1991). Resources were not equally available to all. Meat did not figure prominently in the diets of many individuals, although it was an important component of the diets of the Roman upper classes (Garnsey 1999). Large herds of sheep and goat were reportedly kept predominantly for secondary products, such as wool and milk to produce cheese (Dalby and Grainger 2012; Garnsey 1999). Archaeologically, sheep, goat and pig appear to have been the primary sources of meat (Prowse et al. 2005). Cattle may have been reared primarily for use in traction (Garnsey 1999).

Salt fish and fish sauces and pastes were produced in quantity in the Roman provinces of Spain and continued to be economically important into the Byzantine period (Ponsich and Tarradell 1965; Garnsey 1999; Shepard 2004). In AD 301 the Edict of Diocletian V. 1-5 likely led to the reduced cost of freshwater fish across the Roman Empire (Rutgers et al. 2009) and this may in turn have resulted in social widening of access to fish and fish products. However, consumption of fish in Roman society was often related to status. Fish products, such as *garum* made from tuna fish, were luxury foods with many elites having access. For members of the lower echelons of Roman society, fish products were a difficult resource to obtain (Corcoran 1963; Garnsey 1998). In northwestern Spain, evidence of salting facilities has been uncovered for processing and preserving seafood dating back to the Iron Age. Historical sources during the Late Roman and Medieval periods suggest that a local marshland was exploited heavily for salt production (Lopez Costas and Muldner 2016). Local salting facilities on the Balaeric islands have not been extensively studied. There may have been more localized fish consuming practices on the islands and therefore large-scale salting activities may not have been a priority during the Late Roman period. From the work conducted by Ramon Torres et al. (2012) it appears that at the site of Sa Caleta, Phoenicians were actively extracting salt, which turned into a prosperous industry by around 650BC. Therefore, Ibiza has strong ties to trade within the Mediterranean, carrying over to Roman and Early Byzantine exchange networks.

3.2 Stable Isotope Analysis

Carbon and nitrogen stable isotope ratios of bone collagen have been demonstrated to be reliable indicators of long-term dietary protein intake (Sealy 2001, Schoeninger 2010). $\delta^{13}C$ and $\delta^{15}N$ isotope values of different categories of foods (e.g. marine and freshwater foods, and terrestrial resources from C_3 and C_4 plant foodwebs) are generally distinctive. Plants in different environments (terrestrial, marine and freshwater) fix/acquire carbon during photosynthesis in different ways. Plants utilized as dietary staples fix carbon by one of two pathways, either the C_3 or C_4 pathway. C_3 plants comprise most grasses and plants native to temperate regions, including oats, barley, wheat, and rice. C_4 plants include important cereal staples such as maize and millet. C_3 plants generally have lower $\delta^{13}C$ values than C_4 plants. For example, a typical consumer of foods drawn from the terrestrial C_3 foodweb might have $\delta^{13}C$ values between approximately -20‰ and -18‰, while a consumer entirely dependent on resources from the C_4 foodweb would be anticipated to have $\delta^{13}C$ around -7.5‰ (cf. van der Merwe and Vogel 1978; Tykot 2004). Marine plants also fix carbon by the C_3 pathway. However, the $\delta^{13}C$ values of marine plants are distinctive from terrestrial C_3 plants because marine carbon isotope ratios are enriched relative to atmospheric carbon isotope ratios (Tykot 2004). A typical consumer of predominantly marine resources might have isotope values of $\delta^{13}C$ = -12‰. Although this overlaps with the carbon isotope values of C_4 consumers, the two dietary components can *often* be distinguished by $\delta^{15}N$ analysis.

Nitrogen stable isotopes are enriched with each trophic level by at least c. 3-5‰ (Bocherens and Drucker 2003) and potentially up to 6‰ (O'Connell et al. 2012). Human consumers of terrestrial resources will typically have $\delta^{15}N$ values c. 6-10‰ (Tykot 2004). Marine/freshwater food-chains are generally longer than terrestrial food-chains so consumers of aquatic resources tend to have higher $\delta^{15}N$ values than consumers of terrestrial resources (although see Hedges and Reynard [2007] for discussion of uncertainties in $\delta^{15}N$ trophic shift variation). This $\delta^{15}N$ difference between terrestrial and aquatic food-chains generally allows diets based on marine resources to be distinguished from those derived from the C_4 foodweb.

Co-analysis of $\delta^{13}C$ and $\delta^{15}N$ signals of humans and fauna may distinguish between diets based on terrestrial C_3 and C_4 plant foodwebs, freshwater and marine resources, and identify the trophic level of the consumer (e.g. Chisholm et al. 1982; Schoeninger and DeNiro 1984; Tykot 2004).

4. Materials and Method

Bone samples for stable isotope analysis were obtained from the individuals that were relatively well preserved in comparison to most the human bone material recovered. In the case of comingled remains only one sample was taken to ensure that there was no duplication in sampling. A total of 38 individuals were sampled (see Table 1), comprising 12 males, 8 females and 18 individuals of unknown sex. Twenty-two of these individuals are adults; one is a juvenile and 15 are of unknown age.

A sample of approximately 1 g of bone was taken from each specimen. Pre-treatment consisted of cleaning each sample with the removal of 1-2 mm of surface bone. This was done to eliminate remnant external contaminants accumulated while buried (van Klinken and Hedges 1995). Cancellous bone was removed from samples taken from the long bones. Collagen was extracted from all samples using a modified version of the Longin (1971) method (Brown et al. 1988).

Each sample was demineralized in 1 N HCl at 20°C for a minimum of 24 hours, and gelatinized in 0.03 N HCl at 80°C for approximately 16 hours. The resulting solution was then lyophilized. Well-preserved collagen samples, i.e. those with %wt yield of >1.00% (van Klinken 1999), were measured for $\delta^{13}C$ and $\delta^{15}N$ by the SUERC Radiocarbon Laboratory in East Kilbride, UK, using a Costech ECS 4010 combustion elemental analyzer coupled to a Thermofisher Delta V Advantage gas source isotope ratio mass spectrometer. In-house gelatine standards, which are calibrated to the International Atomic Energy Agency (IAEA) reference materials USGS40 (L-glutamic acid, $\delta^{13}C_{V\text{-}PDB} = -26.39‰$), USGS41 (L-glutamic acid, $\delta^{13}C_{V\text{-}PDB} = +37.63‰$), IAEA-CH-6 (sucrose, $\delta^{13}C_{V\text{-}PDB} = -10.45‰$), USGS25 (ammonium sulphate, $\delta^{15}N_{AIR} = -30.41‰$), IAEA-N-1 (ammonium sulphate, $\delta^{15}N_{AIR} = +0.43‰$) and IAEA-N-2 (ammonium sulphate, $\delta^{15}N_{AIR} = +20.41‰$), are run in duplicate for every ten unknown samples. Results are corrected for linearity and instrumental drift, and are reported as per mil (‰) relative to the internationally accepted standards V-PDB and AIR, with 1σ precisions of ± 0.2‰ and ± 0.3‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively.

Collagen integrity was assessed by the following criteria: (i) atomic C:N ratio in the range 2.9 to 3.6 (DeNiro 1985), and (ii) minimum %C = 13% and %N = 5% (Ambrose 1990). All the samples discussed below met these criteria.

Comparison of human stable isotope values with those of potential food sources improves the accuracy of dietary models. However, no faunal remains were recovered from the Joan Planells cemetery. The Joan Planells data were therefore compared to published archaeological faunal stable isotope values from the near-contemporary site of S'Hort des Llimoners also located at Eivissa, Ibiza (see Table 2, data from Fuller et al. 2010).

5. Results and Discussion

The $\delta^{13}C$ and $\delta^{15}N$ isotope values of the Joan Planells human bone samples are presented in Table 1 and in Figures 2 and 3. Mean±standard deviation (1σ) $\delta^{13}C$ and $\delta^{15}N$ values of the sampled population (n=38) are -18.7±0.5‰ and 10.1±1.3‰, respectively. In a Mediterranean population, these values are consistent with a diet based largely, but not necessarily exclusively, on terrestrial C_3 resources including meat and dairy produce (e.g. Richards et al. 1998; Tykot 2004). Comparison with Late Antiquity–Early Byzantine (LA-EB) animal isotope data (from Fuller et al. 2010) to set baseline values for the local foodweb suggests that animal protein was a noteworthy component of average diet but that additional resources, such as cereals, were likely to have been important dietary staples – see Table 2 and Figure 3. The average $\delta^{15}N$ value of the Joan Planells individuals is 4.6‰ above the caprine mean $\delta^{15}N$ value (of 5.5‰, n=8), 4.3‰ above the pig mean $\delta^{15}N$ value (of 5.8‰, n=2) and 2.6‰ above the cattle mean $\delta^{15}N$ value (of 7.5‰, n=2). Caprine and porcine products may therefore have played a more important role in human diet than those of cattle. This corresponds not only to the reported dominance of goat in the animal remains recovered from Late Antiquity-Early Byzantine sites in Ibiza but also to accounts of Roman period diet, which point to greater dependence on pork (Fuller et al. 2010).

The higher mean $\delta^{13}C$ value of humans compared to animal food-species (-18.7‰ in humans in comparison to -20.1‰ in cattle, pigs and caprines) is statistically significant (Mann-Whitney U Test $\delta^{13}C$, U=32.5, $p<0.05$ – see Table 3 for all p-values and U statistics). This may reflect additional or distinctive protein sources in human diet (e.g. a small component of C_4 resources) or, alternatively, may be the result of a $\delta^{13}C$ food-consumer offset. Bocherens and Drucker (2003) argued that the $\delta^{13}C$ trophic level shift between 'predator' and 'prey' could be up to 2.0‰. Notably, the food species dataset from S'Hort des Llimoners is limited, comprising a total of 12 specimens from three taxa. It is therefore possible that the observed difference in human and domesticate $\delta^{13}C$ values is an artefact of sample size.

TABLE 1 HERE

FIGURE 2 HERE

FIGURE 3 HERE

TABLE 2 HERE

TABLE 3 HERE

5.1 Limitations of Study

This study serves to add to the growing body of research on dietary trends during the Late Roman period of the Balearic Islands. Fuller et al (2010) provide an extensive diachronic perspective from various sites on Ibiza and Formentera, with human and animal isotopic signatures being gathered. Within the scope of our project, and with the resources available to the authors on site context information as well as historical correlates, the project does suffer from a lack of local animal signatures to tease apart the human signatures and the sources of dietary consumption as well as provide a stronger connection to the kinds of biocultural and historical processes that may have been impacting diets between men, women and children. In addition to this, the burials available to analyze for isotopic signatures were limited to 38 individuals, as there was some poorly preserved remains from the cemetery of Joan Planells. Furthermore, due to the limited contact with the original excavators there is not as much in-depth contextual information that could be added to the background and interpretations of dietary practice at this site. This limitation is a testament to the necessity of osteological specialists to be present during excavations and for more conversations to occur during and after the recovery of the material from the field.

Despite these limitations, the study allows for comparisons to be made more closely among men and women from Joan Planells, which is a greater step towards discussing gendered dietary trends in the past. This kind of conversation allows for more nuanced interpretations to be made about the ways that Romanization were influencing frontier sites at the confluence of the Roman and non-Roman world.

5.2 Differences in individual diets

At Joan Planells stable carbon isotope ratios have a relatively narrow range of values from -17.7‰ to -19.7‰ (within ±1‰, which DeNiro and Schoeninger [1983] identified as the typical range for populations consuming uniform diet). The range of the $\delta^{13}C$ values is consistent with a predominantly C_3 foodweb-derived diet for *this* region. C_3 plants are reported to have mean $\delta^{13}C$ of -26.5‰ (e.g. Tykot 2004): assuming a diet-bone collagen offset of +5‰, consumers of an exclusively C_3 derived diets would be anticipated to have $\delta^{13}C$ values of c. -21.5‰. However, C_3 cereals from the West-Mediterranean region of Spain have been demonstrated to be relatively ^{13}C-enriched. Archaeological specimens of *Triticum durum*, *Hordeum vulgare* and *Hordeum vulgare nudum* recovered from Neolithic to Iron Age contexts have mean $\delta^{13}C$ values of -22.6‰, -22.8‰ and -22.6‰, respectively (see table 1, Araus et al. 1997). Consumers of these C_3 resources would have $\delta^{13}C$ values of c. -17.7‰.

The nitrogen isotope ($\delta^{15}N$) values exhibit a wide range from 9.0‰ to 14.8‰ spanning approximately one trophic level (O'Connell et al. 2012), suggestive of individual differences in dietary intake. It should be noted, however, that most of the sampled population have $\delta^{15}N$ values of ≤12.7‰. Two males, UE303 and UE301, are statistical outliers with especially high $\delta^{15}N$ values of 14.4‰ and 14.8‰, but typical $\delta^{13}C$ values of -18.6‰ and -19.1‰, respectively. This suggests that the diet of these individuals was distinctive from other members of this group. Increased $\delta^{15}N$ values are typical of diets that include aquatic resources such as fish and sea mammals. Generally, consumption of marine resources is associated with the co-linear increase of both $\delta^{13}C$ and $\delta^{15}N$ values (Schoeninger et al. 1990). Spearman's Rank Order Correlation test indicated a moderate positive correlation (r_s=0.37) between the $\delta^{13}C$ and $\delta^{15}N$ values in the Joan Planells population (see also Figure 2). Arguably, however, $\delta^{15}N$ values are a more reliable indicator of marine resource consumption than $\delta^{13}C$ in Mediterranean populations where diets may be relatively high in carbohydrate and low in protein (Prowse et al. 2005; Craig et al. 2013). In individuals with relatively low protein diets nutrient scrambling (Prowse et al. 2004; Craig et al. 2013) may result in carbon and nitrogen being drawn from different dietary constituents – carbon may be assimilated from dietary proteins, carbohydrates and/or lipids in protein inadequate diets (Hedges 2004). It is likely therefore that the ^{15}N-enriched values of individuals UE301 and UE303 are the result of increased access to aquatic/marine resources, which may be status- or activity-related. This interpretation is offered cautiously – in the Mediterranean region identifying the consumption of marine foods is non-trivial. Among the men of Joan Planells, there is a stepwise, linear pattern that shows there is incremental differences in $\delta^{15}N$ values, while $\delta^{13}C$ values are almost the same (Figure 2) (positive linear trend is highlighted by a ~~vertical~~ dashed red line). This pattern may be suggestive of differential access to fish resources among the men of this population and that possibly there were men of highly distinct statuses being buried in the same cemetery. The $\delta^{13}C$ and $\delta^{15}N$ values of fish from the Mediterranean Sea vary widely (see Pinnegar and Polunin 2000; Garvie-Lok 2001; Polunin et al. 2001; Badalamenti et al. 2002; Prowse et al. 2004; Keenleyside et al. 2009). Polunin et al. (2001) reported that the mean $\delta^{13}C$ and $\delta^{15}N$ values of modern fish specimens captured off the southeast coast of Ibiza were -17.8‰, much lower than the $\delta^{13}C$ range (-8.3‰ to -14.1‰) for modern and archaeological Mediterranean fish published by Garcia-Guixé et al. (2010).

The mean±s.d. (1σ) $\delta^{13}C$ and $\delta^{15}N$ values of the females (n=8) at Joan Planells are -18.3±0.5‰ and 11.5±0.8‰, respectively, while those of the males (n=12) are -18.9±0.3‰ and 11.3±1.7‰, respectively. There is a statistically significant difference between male and female $\delta^{13}C$ values, but not in $\delta^{15}N$ values, even with the statistical outliers included (Mann-Whitney U Test $\delta^{13}C$, $U=19.5$, $p<0.05$; $\delta^{15}N$, $U=64.5$, $p>0.05$). This difference along with isotopic signatures for an increased preponderance of degenerative conditions may point to activity and/or sex-based differences in access to food. The parsimonious explanation for relative ^{13}C-enrichment in females with no associated increase in $\delta^{15}N$ values is a greater contribution of C_4 plant resources to diet (cf. Müldner et al. 2011 and Pickard et al. 2017). Millet, a C_4 cereal, may have contributed to the diets of Late Roman-Early Byzantine interred on Ibiza (e.g. Fuller et al. 2010). An alternative possibility is the consumption of low trophic level aquatic/marine resources such as shellfish and garum made from low trophic level fish. For example, stable isotope values of samples of garum from Roman Pompeii have high $\delta^{13}C$ values (-12.2‰) and relatively low $\delta^{15}N$ values (4.9‰) (Pate 2016). Similar mean values are quoted by Prowse et al. (2004) for five ancient garum samples, with $\delta^{13}C$=-14.7±0.6‰ and $\delta^{15}N$=6.5±1.7‰. Hedges (2004) indicated that as much as 20% of dietary protein would need to be drawn from marine resources for this component of diet to be isotopically visible. Given an average daily requirement of c. 50 g of protein in females and traditional Southeast Asian fish sauces, which are considered to "parallel almost exactly" garum, have a protein content of 100g/L (see Curtis 2009), consumption of 100 ml of garum per day should be isotopically visible. Additionally, in carbohydrate rich diets that are relatively low in protein, protein-rich foods can make a disproportionate contribution to collagen isotope signals reflecting amino acid routing as opposed to biosysnthesis (Webb et al. 2016).

5.3 Demographics and diet

A further consideration in isotope-based dietary reconstruction is the structure and 'isotope age' of the population sampled. The Joan Planells bone collagen samples were obtained from individuals of varying age as well as from different skeletal elements (including long bones, digits and ribs) The isotope signatures of these individuals therefore potentially reflect diet at different stages of life and over varying timespans. The timespan reflected in bone collagen stable isotope values depends on (i) the age of the individual at death, and (ii) the type of bone sampled, i.e. whether it is trabecular or cortical tissue. In infants and young children there is rapid bone development and sampled bone collagen may reflect diet only during the year prior to death (Tsutaya and Yoneda 2013). During adolescence, another key period of substantial bone growth, complete collagen turnover may occur in both trabecular and cortical bone in as little as one to two years (Ubelaker and Parra 2011; Tsutaya and Yoneda 2013). In adulthood, with cessation of bone growth, collagen turnover reduces significantly – it is estimated to take, on average, between 10 and 30 years for collagen to turnover completely (Libby et al. 1964; Stenhouse and Baxter 1979; Hedges et al. 2007). Consequently, in young to middle aged adults there is disproportionate representation of dietary intake during adolescence in bone collagen isotope signatures depending on skeletal element sampled (Hedges et al. 2007; Ubelaker and Parra 2011). Collagen turnover in cancellous elements is generally more rapid than that in cortical tissues. Collagen in adult ribs may turnover completely in as little as c. 2 years and in vertebrae in 1-3 years, while turnover in the mid-shaft of an adult femur may take over 20 years (Bryant & Loutit 1964; Hedges et al. 2007).

The majority of the aged individuals sampled at Joan Planells fall into the young to middle adult categories. In these individuals analysis of cortical bone would be anticipated to mainly reflect dietary intake during adolescence, while analysis of largely cancellous bone tissue should reflect diet in the last 2-5 years before death. Comparison of cortical vs cancellous elements indicated no significant difference in $\delta^{13}C$ nor in $\delta^{15}N$ values (Mann-Whitney U Test $\delta^{13}C$, $U=227.5$, $p>0.05$; $\delta^{15}N$, $U=170.5$, $p>0.05$) suggesting that dietary intake did not change significantly between adolescence and adulthood.

Notably, 88% of the females analyzed were of reproductive age. A range of factors, including pregnancy as well as nutritional stress and pathological conditions can result in non-dietary related variation in individual $\delta^{13}C$ and $\delta^{15}N$ values (e.g. Fuller et al. 2005; Nitsch et al. 2010; Olsen et al. 2014).

5.4 Diet in the Late Antiquity-Early Byzantine period – a stable isotope perspective

Diet of the Late Antiquity-Early Byzantine cemetery population at S'Horts des Llimoners is broadly like that of the Joan Planells population, with primary dependence on C_3 resources and potentially with a small component of C_4 or marine resources (Table 4; Fuller et al. 2010). Given the proximity contemporaneity of the two sites the similarity in diets is perhaps not unexpected. However, differences in minor components of diet are evident. While the $\delta^{15}N$ values of the adult populations at Joan Planells (n=23) and S'Horts des Llimoners (n=34) are statistically indistinguishable, there is a significant difference in the $\delta^{13}C$ values (Mann-Whitney U-test, $\delta^{13}C$, U=525.5, $p<0.05$: $\delta^{15}N$, U=402, $p>0.05$). The relative ^{13}C-enrichment of the Joan Planells adult population compared to that of S'Horts des Llimoners lends support to the suggestion that a C_4 resource, such as millet, may have contributed to diet at Joan Planells, and possibly more among women of this population. Alternatively, this difference may reflect more complex patterns of dietary difference resulting from macronutrient scrambling in carbohydrate rich diets that include marine protein (e.g. Prowse et al. 2005; Craig et al. 2013).

TABLE 4 HERE

It is apparent that there was no one 'Roman' diet in both Italy, mainland Spain and the Balearic Islands (Killgrove and Montgomery 2016). Direct comparison of stable isotope values and diets at Late Roman sites in other regions is limited by the demonstrably different baseline isotope values of domesticates across these regions (e.g. Prowse et al. 2004; Keenleyside et al. 2009; Craig et al. 2009; Rissech et al. 2016). However, some general observations can be drawn.

Dependence on C_3 plants, with an important but variable contribution from meat and/or dairy products, is characteristic of many Late Roman sites in the sphere of Roman influence and on mainland Spain and throughout the Mediterranean Basin (e.g. Killgrove and Tykot 2013; Rissech et al. 2016; Salazar-García et al. 2016; Saragoça et al. 2016). The range and relative importance of the foods consumed at S'Horts des Llimoners and Joan Planells are remarkably like the diets inferred for individuals interred at the Late Roman cemeteries of Casal Bertone and Castellaccio

Europarco, Rome, Italy (see Killgrove and Tykot 2013). At each of these sites diet was based principally on C_3 plants with meat/other animal products, while C_4 and/or aquatic resources minor contributors to diet. However, interestingly this pattern is reverse for mainland NW Spain, which shows high consumption of fish and C4 resources (Lopez-Costas and Muldner 2016).

As at Joan Planells, caprines and pigs were likely the primary sources of animal protein at the late Roman necropolis at Carrer Ample 1, Barcelona, Spain. Rissech et al. (2016) highlighted the distinctive nature of diet at Carrer Ample 1 in comparison to other Late Roman sites in the Mediterranean owing to the slight or absent contribution of fish at this coastally located site. The $\Delta^{15}N$ spacing of 6.4‰ between humans and domesticates is relatively high at Carrer Ample 1, larger than one trophic level (O'Connell 2012) – see Table 5. The likely contribution of fish to diet at Carrer Ample 1 thus appears to be greater than that at Joan Planells or Casal Bertone and Castellaccio Europarco. This interpretation is complicated by the single chicken bone analyzed from Carrer Ample 1, which has a $\delta^{15}N$ value of 10.8‰. However, broadly Carrer Ample 1 fits the C_3-dominated dietary pattern evident at many other sites.

Although discerning the role of marine resources in Mediterranean diet in Antiquity is complex, the stable isotope evidence, at least at the population level, points to little contribution of fish to diet at many sites (e.g. Fuller et al. 2010; Killgrove and Tykot 2013; Rissech et al. 2016; and see Table 5). These patterns differ from those seen in Late Roman contexts at A Lanzada in Galicia, where there is frequent consumption of local fish species (Lopez-Costas and Muldner 2016). A Lanzada has some of the most C^{13}-enriched values observed in any Iberian population. There is furthermore a significant shift in diet between the Roman and post-Roman period during the 2nd and 4th centuries AD where there is economic and environmental transformation. Archaeological and/or osteological indicators at sites such as Carrer Ample 1, Castellaccio Europarco, as well as Joan Planells, suggest that the interred populations were generally of low socio-economic standing (Killgrove and Tykot 2013; Rissech et al. 2016). However, some of the individuals interred at these sites do have ^{15}N-enrichment consistent with a greater, and in some instances, a sizeable proportion of fish in diet (e.g. UE 301 and UE303 at Joan Planells) These two male individuals are both in their 20s or 30s and their graves were single cist burials with undifferentiated artifacts. Perhaps these were individuals who had direct connections with the fishing industry?

TABLE 5 HERE

An alternative hypothesis is that individuals of higher status had greater access to prestige foods. Prowse and colleagues (2004) demonstrated that the affluent population of Portus Romae, interred at Isola Sacra, consumed a significant proportion of fish, with up to 40% of dietary protein derived from marine resources. In contrast to this, the rural, inland, farming population from the cemetery at an ANAS excavated site in Rome's suburbs had relatively low ^{13}C and ^{15}N reflecting the minor importance of fish to diet (Prowse et al. 2004). However, this correlation between status and fish consumption if far from universal. At the contemporary trading port of Velia, in southern Italy, Craig and colleagues (2009) identified variation in access to marine resources: this could not be clearly linked to status inferred from burial style. As Craig et al. (2009) pointed out there is no evidence to support the notion that the individuals interred at Isola Sacra were of higher status than the population at Velia. Craig et al. (2009) therefore concluded that the increased consumption of fish evident at Isola Sacra did not directly reflect status but was specific to the economy, occupations and access to traded foods of those employed at one of the largest trading ports in the Roman world.

Differences in the diets of males and females are suggested by stable isotope ratios at Isola Sacra, Velia and Joan Planells (Prowse et al. 2005; Craig et al. 2009). At each of these sites females appear to consume more plants, while males have greater access to either meat or fish. This trend is evident also in the pre-Roman, Celtic population from the necropolis of Seminario Vescovile in Verona, dating from the 3rd to 1st century BC, which indicates that women consumed higher amounts of C4 plants (and cereals in general), while men had greater access to meat (Laffranchi et al. 2016). For cultural and practical reason men in Roman society generally had greater access to higher prestige food such as meat and fish. Socio-economic status may have influenced the manifestation of dietary differences. The effects of sex-based dietary restrictions would have been more pronounced in wealthier households. All members of lower status households, male and female would have had limited access to meat (Garnsey 1999). The cultural restriction of certain foods based on the perceived negative effects on health in females may have permeated the social makeup of the colonies.

Dietary differences between males and females at Joan Planells hint at greater consumption of a C_4 resource. The stable isotope values of the domesticates from S'Horts des Llimoners show no evidence for a C_4 component in animal feed. Thus, if sex-based dietary differences at Joan Planells reflect C_4 input, it is likely that this was in the form of the C_4 cereal millet. Stable isotope analyses have indicated that the consumption of millet was widespread in later prehistoric and Roman Europe and that it correlated with socio-economic status (e.g. Murray and Schoeninger 1988; Bonsall et al. 2004; Le Huray and Schutkowski 2005). In Roman society millet was viewed as a poor-quality cereal (Iacumin et al. 2014; Kulikowski 2004), not used in the kitchens of the elite, and often grown for animal fodder (Adamson 2004). Millet flour was also used to produce bread and a sort of porridge cooked in water and salt. Often, these kinds of foods were accompanied by vegetables and cheese and very rarely with meat (Columella, *De Re* Rustica, 2, 9, 14-16; Pliny the Elder, *Naturalis* Historiae XVIII, 83-84; Lafrranchi et al. 2016). Cemetery sites in the locus of Rome confirm the correlation between millet intake and socio-economic status. At the more rural, suburban cemetery of Castellaccio Europarco consumption of millet was greater than at the urban cemetery of Casal Bertone – this is reflected in relative ^{13}C at the former site (Castellaccio Europarco adult δ^{13}C= -17.8±2.6‰ and δ^{15}N=9.4±1.4‰; Casal Bertone adult δ^{13}C=-18.2±0.6 and δ^{15}N=10.0±1.5‰).

The evidence from Joan Planells spans the 3rd to 7th centuries AD and the isotopic signatures are evaluated at the site level. This means that the population average for δ^{13}C and δ^{15}N values account for the entire spread of this timeframe. While most the burials are from the 3rd to 5th centuries, the later 7th century evidence may present some variability among the trends for this Late Roman period. Nevertheless, the dataset is an important contribution to discuss how diet can differ not only between geographically closer locales, such as Joan Planells and A Lanzada in mainland Spain, but also how diet can vary within a population, in which two men have significantly higher δ^{15}N values than the rest of the population.

The discussion above highlights the clear similarities between the diet, and potentially cultural restrictions that limit access to foods, at Joan Planells and other sites both in Italy and in the sphere of Roman influence on mainland Spain and the Balearic Islands. However, to determine if these similarities are the result of Roman influence comparisons must be made with pre-Roman diet on Ibiza. The diet of the Joan Planells adult population is distinctive from that of the earlier Punic (5th-2nd/1st centuries BC) population from the rural necropolis Ses Païsses de Cala d'Hort (δ^{13}C=-18.7±0.3‰ and δ^{15}N=12.5±0.5‰, n = 38), situated in southwest Ibiza: Fuller et al. 2010). Relative ^{15}N-enrichment is evident at the latter site (Mann-Whitney U test δ^{13}C, U=354, p>0.05;

$\delta^{15}N$, U=135, $p<0.05$) suggesting increased consumption of higher trophic level foods, such as meat and potentially fish or fish products. While it is tempting to attribute this apparent shift in dietary pattern to Roman influence, it is important to acknowledge that there is no difference (Mann-Whitney U test $\delta^{13}C$, U=61.5 $p>0.05$; $\delta^{15}N$, U=71, $p>0.05$) in the isotope values of the Joan Planells population and that of an urban Punic population at Puig des Molins ($\delta^{13}C$=-18.8±0.3 and $\delta^{15}N$=-11.3±0.8, n=6: Fuller et al. 2010). This suggests the diet of urban populations remained largely unchanged in Ibiza through the Punic period and into the Roman period. However, the number of adults sampled for Puig des Molins is very small. Additionally, there was no demographic information available for either the Puig des Molins or Ses Païsses de Cala d'Hort populations so it was not possible to investigate sex-based variability in Punic diet. Further research into dietary variability at Punic and Roman period sites on Ibiza would assist in clarifying the impact of external spheres of influence on local cultural practices.

It is apparent then that the dietary patterns of population at Joan Planells varied internally, but also it varied greatly from the pattern of food consumption in Italy and in mainland Spain during the Late Roman period. Twiss (2007) articulates that food forms the basis of identity politics and forms the basis of sustaining group cohesion and responses to internal and external pressures to a community. For the population of Joan Planells, the negotiation of identity was occurring through the Late Roman context and in the Early Byzantine period, when new internal and external pressures were mounting. This community may have faced environmental and socio-political change that was mitigated by consuming more local, C3 plant resources, instead of engaging with the millet trade and fish acquisition. The ability for this population to negotiate their role in the midst the cessation of Roman influence recognizes the ingenuity and agency for the community at Joan Planells.

6. Conclusions

The results of $\delta^{13}C$ and $\delta^{15}N$ analysis of human bone collagen indicate that the population sampled at Joan Planells consumed a diet based largely on C_3 resources with a possible small contribution from C_4 plants and/or aquatic resources. The $\delta^{13}C$ values of the men and women are statistically significantly different, suggesting dietary and potentially gender-differences. The enriched $\delta^{15}N$ signatures of two males in particular may have implications for status and/or activity-related differences in dietary intake.

This investigation reveals important dietary trends for a region that was in the sphere of Roman influence. The combination of carbon and nitrogen isotopes along with demographic data indicates dietary diversity at Joan Planells. While there are limitations in the detail of archaeological contextual information, these dietary trends at Joan Planells to attest to great variation in subsistence practices and gendered access to food at a time when the Roman sphere was being impacted climatically with surges in extreme storm frequencies as well as greater contact with hostile groups. With the eventual transition to Byzantine dominance in the Mediterranean, these dietary trends reflect the diversity of strategies that may have been practiced during a period of political, economic and social instability. This paper contributes to a more in-depth understanding that scholars have of diet in the Late Roman period, in which no singular dietary trend can be labelled Roman. Better understand the variation in these subsistence signatures can begin to tell us more about local responses to socio-political, economic and environmental changes.

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Table 1: Carbon and nitrogen stable isotope ratio values and collagen quality indicators of the Joan Planells samples.

GUsi	Context ID	Element	Sex	Age	$\delta^{13}C$	$\delta^{15}N$	C/N	%N	%C
2589	JP03 UE324	Scapula	F	17-25	-17.7	12.2	3.2	14.8	40.6
2590	JP03 UE352	Phalanx	M	adult	-18.9	10.2	3.2	15.2	41.8
2591	JP03 UE325	Metacarpal	F	17-25	-17.9	11.3	3.2	14.7	40.1
2592	JP03 UE304	Metacarpal	M	17-24	-18.9	11.2	3.2	15.2	41.7
2593	JP03 UE333	Radius	M	17-35	-18.4	10.9	3.2	10.0	27.7
2594	JP03 UE340	Rib	F	17-44	-18.4	11.3	3.2	12.4	34.4
2595	JP03 UE355	Phalanx	F	17-25	-18.6	11.6	3.2	15.0	40.9
2596	JP03 UE323	Fibula	F	17-35	-18.7	10.3	3.2	15.2	41.6
2597	JP03 UE302	Long bone	M	30-39	-18.2	10.6	3.2	10.3	28.3
2598	JP03 UE357	Long bone	M	>23	-18.9	9.8	3.3	8.2	23.5
2599	JP03 UE303	Long bone	M	25-45	-18.6	14.4	3.2	15.3	42.1
2600	JP03 UE316	Radius	F	22-24	-19.0	12.0	3.2	14.8	40.5
2601	JP03 UE305	Rib	M	21-25	-18.6	11.4	3.2	14.4	39.7
2602	JP03 UE329	Rib	F	17-25	-18.1	12.7	3.2	14.8	40.6
2603	JP03 UE301 201x103	Scapula	M	17-39	-19.1	14.8	3.2	14.9	41.1
2604	JP03 UE349-2	Metatarsal	M	17-39	-18.6	12.1	3.2	16.1	44.0
4707	JP 03 UE 307	Long Bone	UN	UN	-19.3	9.7	3.2	14.1	38.3
4709	JP 03 UE 310	Fibula	UN	UN	-19.1	10.2	3.2	14.8	40.5
4702	JP 03 UE 312	Long Bone	UN	UN	-19.0	9.4	3.2	15.7	43.1
4703	JP 03 UE 314	Long Bone	UN	17-21	-19.7	9.0	3.2	13.7	37.7
4716	JP 03 UE 315	Metatarsal	UN	UN	-19.0	10.4	3.2	15.8	43.0
4712	JP 03 UE 316A	Long Bone	UN	25-45	-19.7	11.5	3.3	14.5	40.5
4706	JP 03 UE 319	Fibula	UN	UN	-18.3	11.1	3.2	13.9	37.9
4720	JP 03 UE 320	Rib	UN	UN	-18.4	9.8	3.2	13.4	36.8
4715	JP 03 UE 321	Fibula	UN	UN	-18.7	10.5	3.2	14.4	39.4
4718	JP 03 UE 329B	Long Bone	UN	19-25	-18.9	12.1	3.2	15.5	42.8
4700	JP 03 UE 332	Ulna	UN	<1	-18.9	9.2	3.2	14.2	39.3
4701	JP 03 UE 334	Long Bone	M?	30-34	-19.3	9.6	3.2	14.4	39.7
4711	JP 03 UE 341-2	Long Bone	UN	25-35	-19.5	10.0	3.3	15.0	41.9
4704	JP 03 UE 344	Metacarpal	UN	25-35	-18.8	9.1	3.2	14.7	40.2
4719	JP 03 UE 346	Fibula	UN	UN	-18.0	12.4	3.2	14.8	40.7
4717	JP 03 UE 347	Humerus	UN	UN	-18.9	10.4	3.2	15.1	41.7
4710	JP 03 UE 348-5	Long Bone	UN	UN	-18.0	12.0	3.2	15.6	42.7
4699	JP 03 UE 352	Phalanx	M	UN	-18.9	10.0	3.2	14.9	40.8
4708	JP 03 UE 354	Metatarsal	F?	UN	-17.7	10.9	3.2	14.6	39.6
4714	JP 03 UE 357	Rib	M?	23-35	-19.0	10.5	3.2	15.4	42.0
4713	JP 03 UE 359	4th Metacarpal	UN	UN	-18.6	9.1	3.2	15.5	42.2
4705	JP 03 UE 405	Radius	UN	UN	-18.7	10.7	3.2	14.8	40.3

Table 2: Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratio values of Late Antiquity-Early Byzantine fauna from S'Hort des Llimoners, Ibiza (data from Fuller et al., 2010).

Sample	Species	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N
IBF 9	Pig	-20.8	5.5	3.4
IB-A-13	Pig	-20.8	6.1	3.2
IBF 10	Sheep/goat	-21.0	5.7	3.3
IBF 8	Sheep/goat	-20.1	4.2	3.3
IB-A-2	Sheep/goat	-20.2	8.7	3.2
IB-A-3	Sheep/goat	-19.8	4.6	3.2
IB-A-4	Sheep/goat	-19.9	5.8	3.2
IB-A-5	Sheep/goat	-20.2	5.5	3.2
IB-A-6	Sheep/goat	-19.8	4.2	3.2
IB-A-14	Sheep/goat	-18.1	5.5	3.2
IBF 11	Cow	-20.3	7.7	3.3
IBF 14	Cow	-19.9	7.2	3.3
IBF 13	Dog	-19.0	9.2	3.3

Table 3: Mann-Whitney p-values, U statistics and indication of statistically significant difference (SSD) data

Variables compared	**p-value**		**U statistic**		**SSD**	
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
trabecular (n= 15) vs cortical (n= 23)	0.100482	0.952372	227.5	170.5	N	N
human (n=38) vs animal-food species (n= 12)	0.000009	n/a	32.5	n/a	**Y**	n/a
Joan Planells males (n=12) vs females (n=8)	0.027891	0.203017	19.5	64.5	**Y**	N
Joan Planells (n=23) vs S'Horts des Llimoners (n=34)	0.028689	0.857998	525.5	402	**Y**	N
Joan Planells (n=23) vs Ses Païsses de Cala d'Hort (n=38)	0.216777	0.000007	354	135	N	**Y**
Joan Planells (n=23) vs Puig des Molins (n=6)	0.686370	0.914252	61.5	71	N	N

Table 4: Comparison of Joan Planells and S'Horts des Llimoners $\delta^{13}C$ and $\delta^{15}N$ values.

Site	$\delta^{13}C$			$\delta^{15}N$			Range		n
	Av.	Max	Min	Av.	Max	Min	$\delta^{13}C$	$\delta^{15}N$	
Joan Planells	-18.7±0.5	-19.7	-17.7	11.2±1.5	14.8	9.0	2.0	5.8	23
S'Horts des Llimoners	-19.0±0.4	-19.7	-18.0	11.1±0.9	12.6	8.3	1.7	4.3	34

Table 5 – Summary data of Roman/Late Roman period sites in the Mediterranean region

Where available the data reflect adult values. For those sites marked with * demographic information was not available.

		Human $\delta^{13}C$			Human $\delta^{15}N$			n	Domesticate $\delta^{13}C$			Domesticate $\delta^{15}N$			n	M vs F
Site	Date	mean	min	max	mean	min	max		mean	min	max	mean	min	max		
ANAS, Rome, Italy*	-	-19.4±0.4	-20.0	-18.9	9.5±1.8	6.9	11.3	14	-	-	-	-	-	-	-	n/a
Carrer Ample 1, Spain	AD 1st-4th C	-18.9±0.3	-19.5	-18.4	11.0±0.4	10.4	11.7	15	-20.4±0.7	-22.0	-19.4	4.6±2.0	1.9	8.7	11	N
Casal Bertone, Rome Italy	AD 2nd-3rd C	-18.2±0.6	-19.5	-16.8	10.0±1.5	7.0	11.8	23	-	-	-	-	-	-	-	N
Castellaccio Europarco, Rome, Italy	AD 1st-3rd C	-17.8±2.6	-19.5	-12.5	9.4±1.4	7.8	11.5	7	-	-	-	-	-	-	-	n/a
Isola Sacra, Rome, Italy*	AD 1st-3rd C	-18.8±0.3	-19.7	-17.8	10.8±1.2	7.5	14.4	105	-21.0	-	-	5.4	-	-	-	Y
Leptiminus, Tunisia	AD 2nd-5th C	-17.8±0.6	-19.0	-16.5	13.0±1.3	10.00	15.7	52	-19.4±1.0	-21.1	-18.3	9.2±2.7	6.0	12.9	6	N
Monte de Cagonha, Portugal	AD 7th C	-18.3±0.3	-18.8	-17.4	10.3±0.7	9.8	13.2	23	-20.2±0.7	-21.3	-18.8	7.1±0.7	6.1	8	10	N
S'Horts des Llimoners	AD 4th-7th C	-19.0±0.4	-19.6	-18.0	11.1±0.9	8.3	12.6	34	-20.1±0.7	-20.8	-18.1	5.9±1.4	4.2	8.7	12	N
St Callixtus, Rome, Italy	AD 3rd-5th C	-19.7±0.4	-20.2	-18.9	10.6±0.5	9.7	11.8	14	-	-	-	-	-	-	-	n/a
Tossal de les Basses, Spain	AD 6th-7th C	-18.2±0.3	-18.7	-17.7	10.8±0.9	8.4	12.2	37	-	-	-	-	-	-	-	N
Velia, Italy	AD 1st-2nd C	-19.4±0.3	-20.0	-18.7	8.7±1.3	6.6	14.1	117	-21.0±1.0	-22.6	-19.1	4.4±1.9	2.6	7.9	8	Y

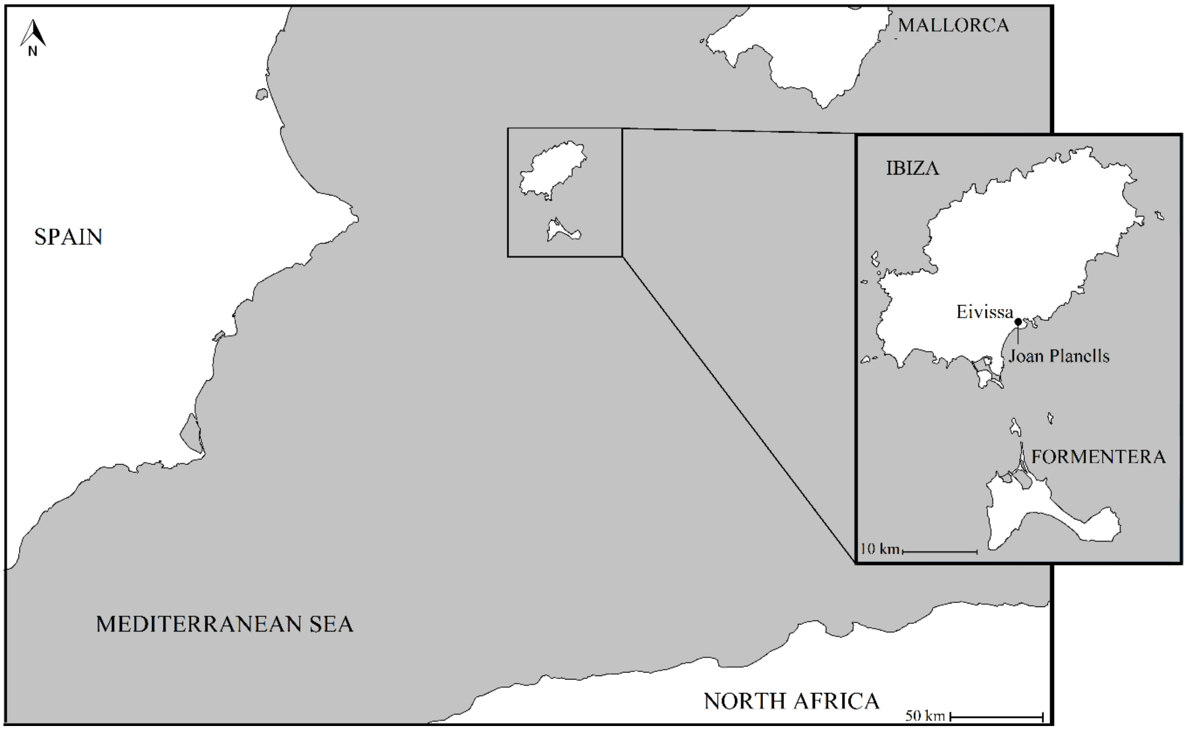
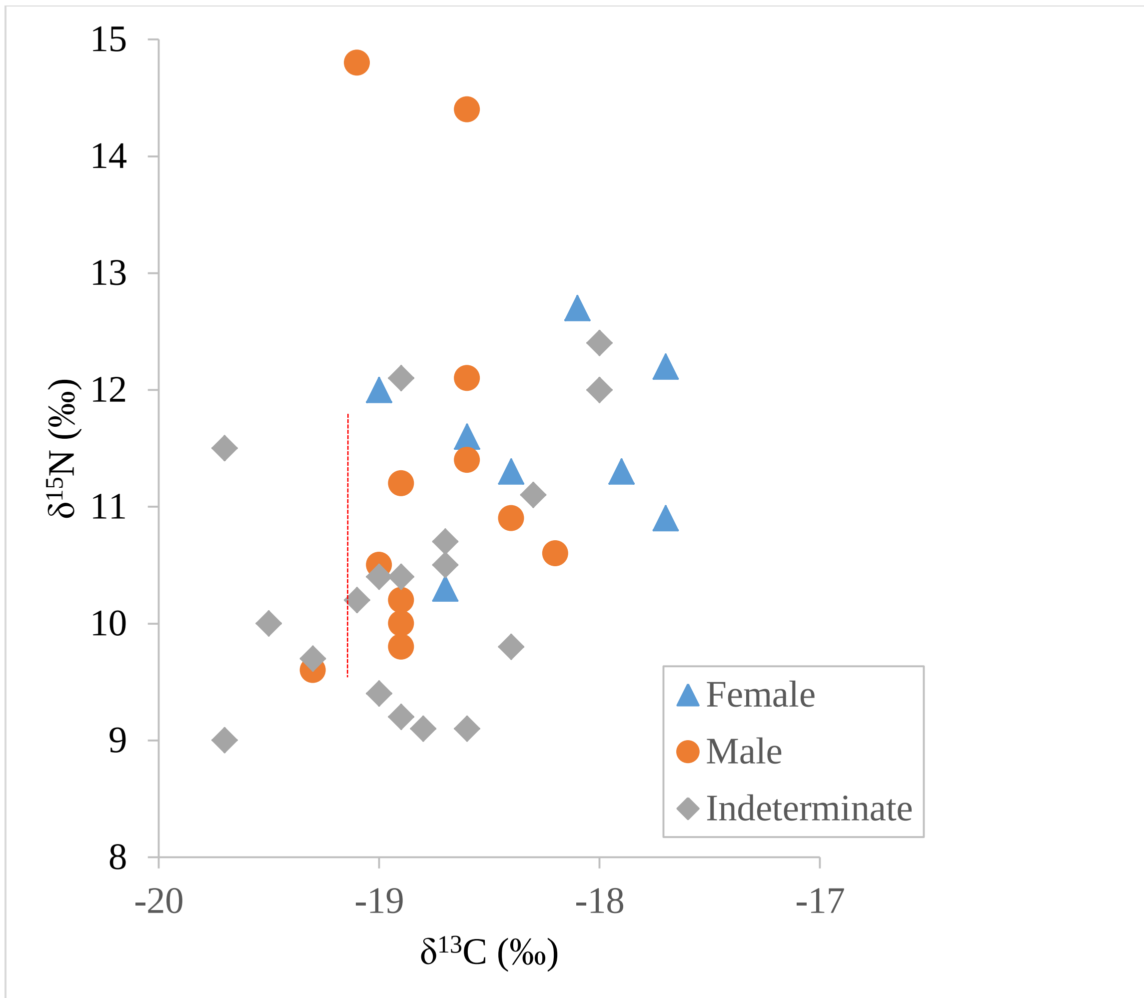


Figure 1: Map of Ibiza with the site of Joan Planells identified.


15
14
13
12
11
10
9
8
-20
-19
-18
-17
δ15N (‰)
δ13C (‰)
Female
Male
Indeterminate

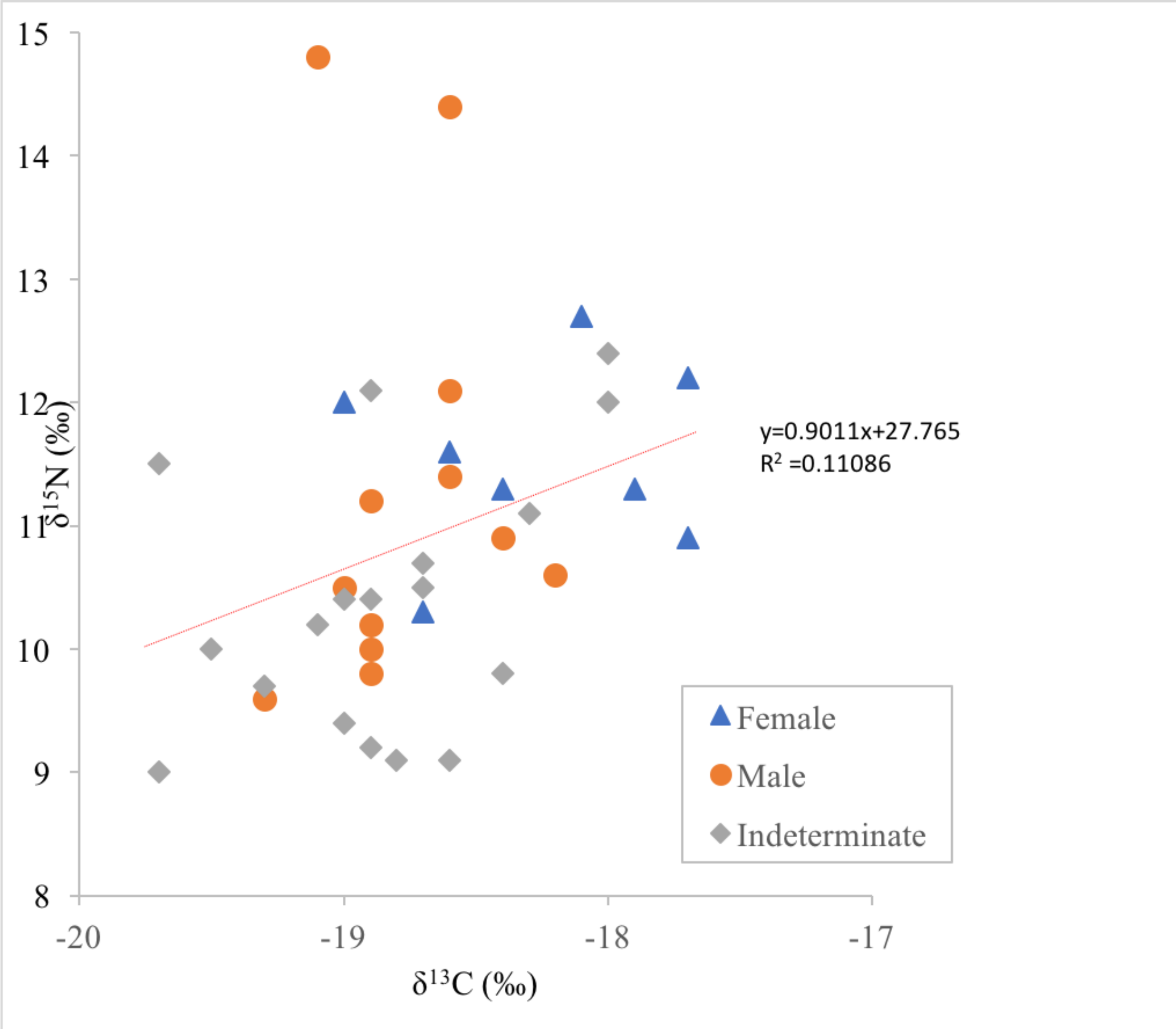


Figure 2: Scatterplot of Joan Planells human $\delta^{13}C$ vs $\delta^{15}N$ values. The positive linear relationship is indicated by the dashed red line. The R^2 value is 0.11086 and the p value is 0.04108 (<0.05).

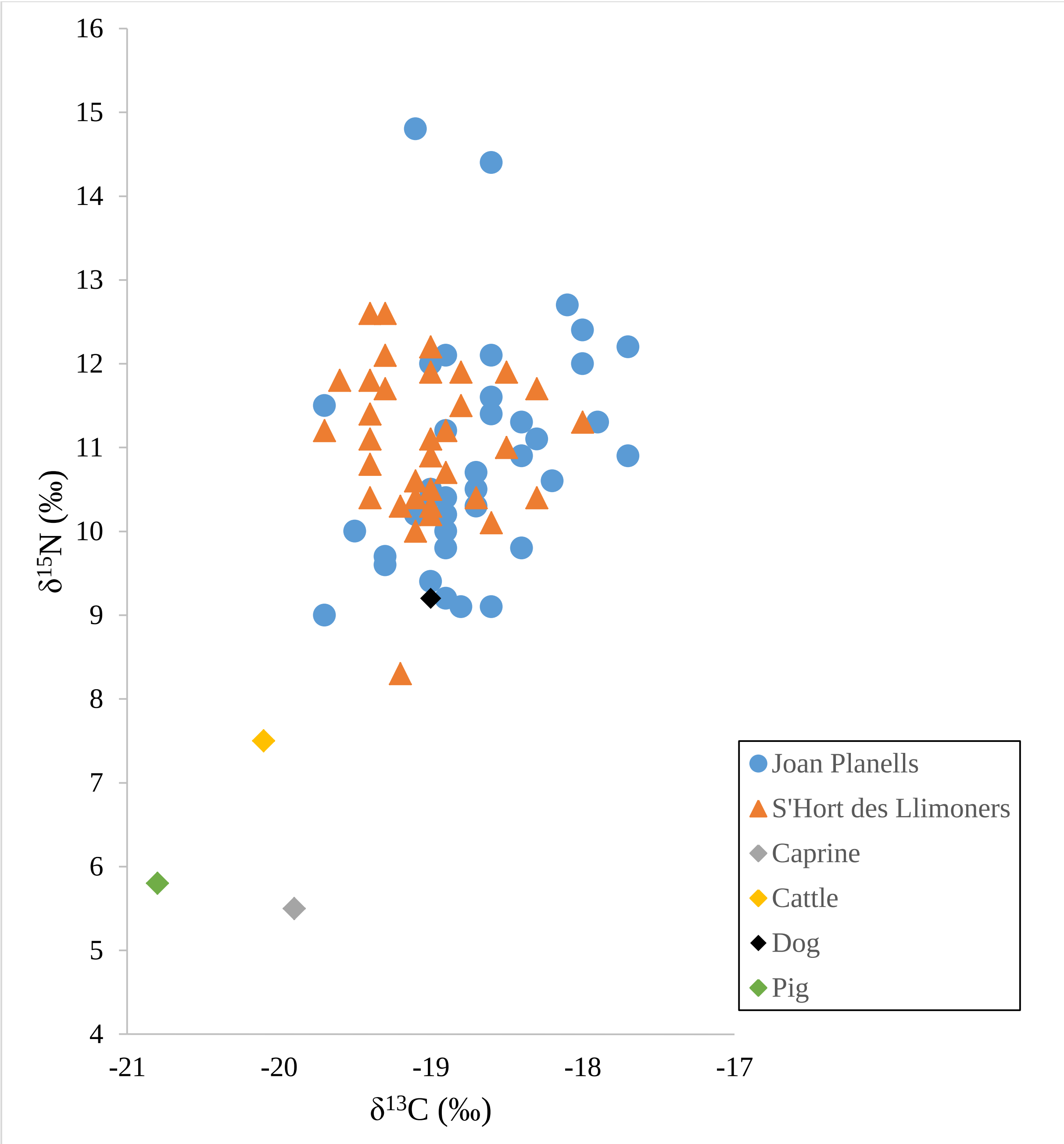


Figure 3: Scatterplot comparing the human remains from Joan Planells with the animal remains from S'Hort de Llimoners (Fuller et al. 2010) – data presented as mean±sd (1σ) where appropriate.